A New Distributed DSP Architecture Based on the Intel IXS for Wireless Client and Infrastructure

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Outline

- Vision for Wireless Networks - ubiquitous
- Anticipated Issues – plethora of "standards"
- Future Wireless Requirements – "soft" with intelligence to increase capacity
- Architectural Objectives – flexible and low power
- How will we go about it? – distributed at the "right granularity"
- Distributed Architectural Summary – based on power, size, and wireless protocols we can derive a "good" (near optimal?) distributed architecture
- Comparison to other Wireless DSP research – flexible but within 2x of Berkeley Research Wireless Center's Pleiades Arch.
- Summary – infrastructure architecture is near-optimum in granularity and power
- Next Steps – client architecture next

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Vision for Wireless Networks

- Ubiquitous Internet Connections for all Mobile Client Devices
  - Handhelds, PDAs, Tablet PCs, and Laptops
  - Always-on
- New Paradigm for Wireless Basestations
  - Proliferation of basestations due to lack of spectrum
  - Agility across Multiple Bands
  - Multi-Network (WLAN, WWAN)

Anticipated Future Issues

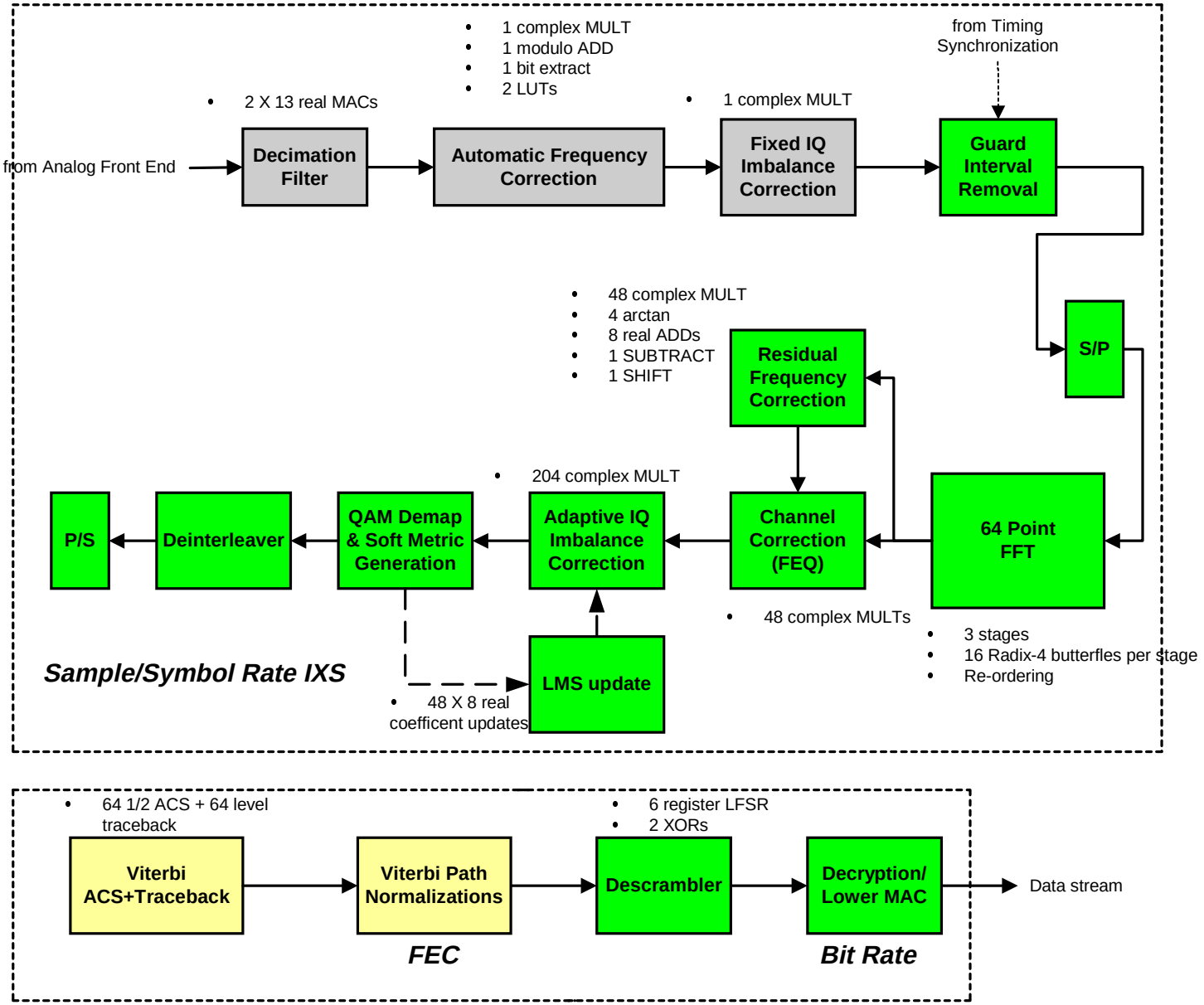
Wireless Protocol Plethora

- PAN, WLAN, and WAN
  - PAN: Bluetooth (UWB, Wireless USB2)
  - WLAN (4 protocols): 802.11b/a (11g, Hiperlan II)
  - WAN (9 protocols):
    - 2G: IS-95, GSM
    - 2.5G: GPRS/EGPRS, cdma2000
    - 3G: WCDMA (FDD, TDD, SC), CDMA 1xE DV

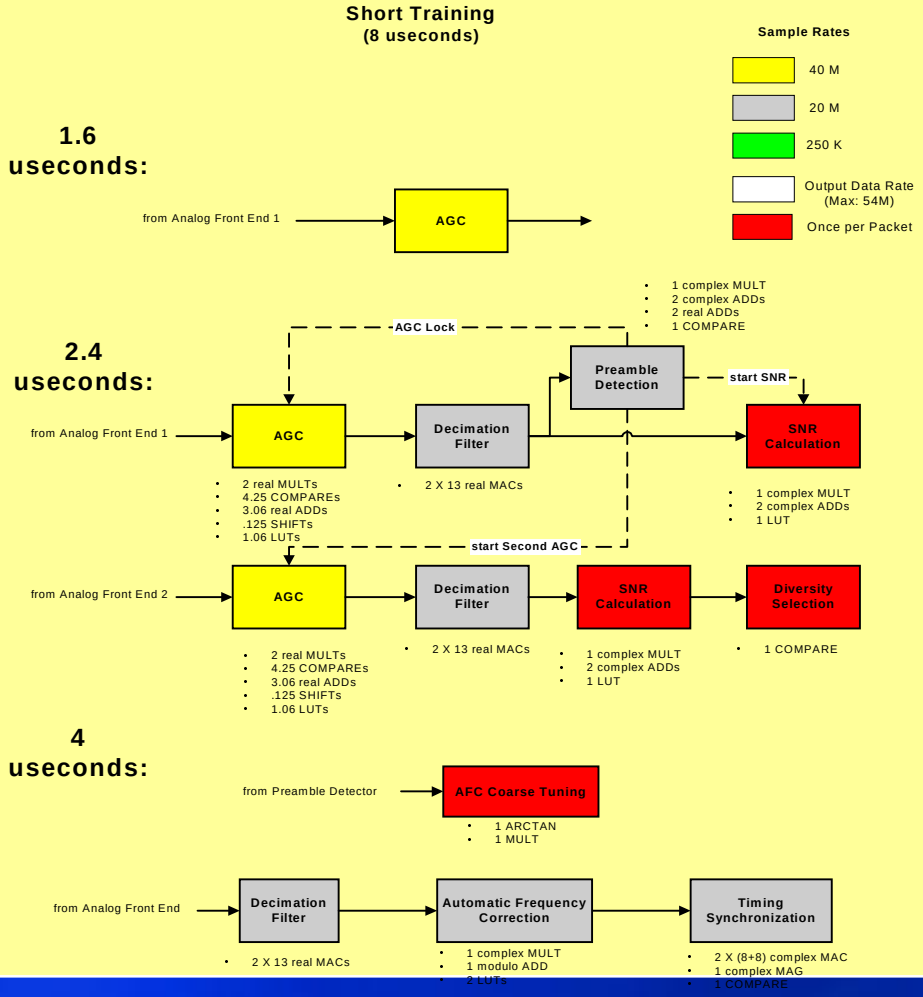
Wireless Requirements Summary

- Soft Radios at Basestations (deployed initially)
  - Low Power (<1 W) but highly flexible
  - Large no. of channels per core
  - Scaleable
- Reconfigurable Client Radios (deployed later)
  - Seamless Client Roaming
    - Two Concurrent Wireless Protocols
    - Selected 802.11a and WCDMA as the most intensive protocols
  - Variable User Environments require “adaptive” resource allocation
  - Adaptive to Broadband AFE distortions
  - Very Low Power (<< 1W)
    - Digital Baseband is < 10% of total PHY pwr
  - Reconfigurable to allow Si Re-use
  - Scaleable

802.11a Signal Processing Flow Example



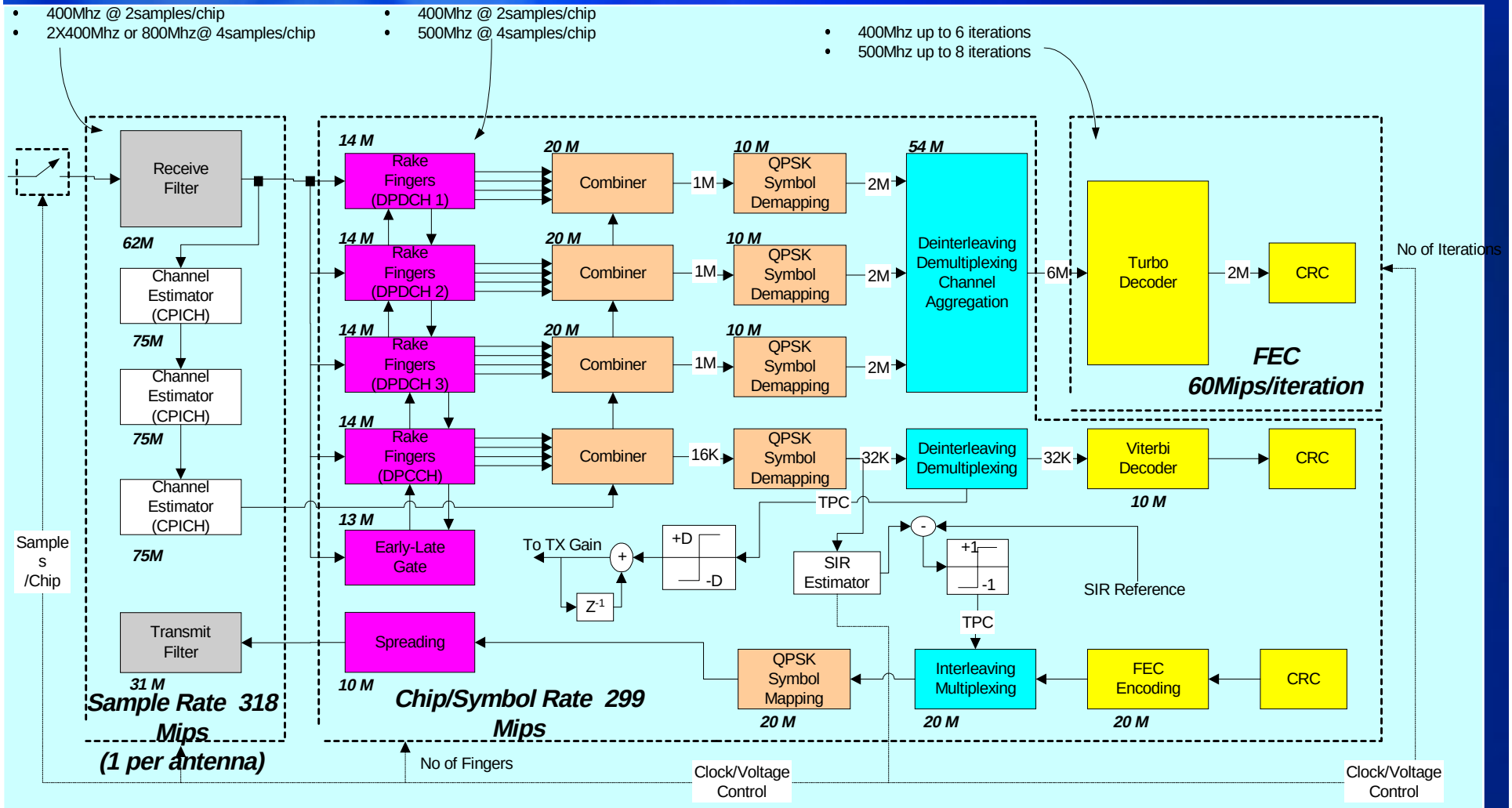
802.11a Initial Acquisition Flow



Hooman Honary

For new Packet Communications schemes – significant processing goes on during very short intervals of the preambles

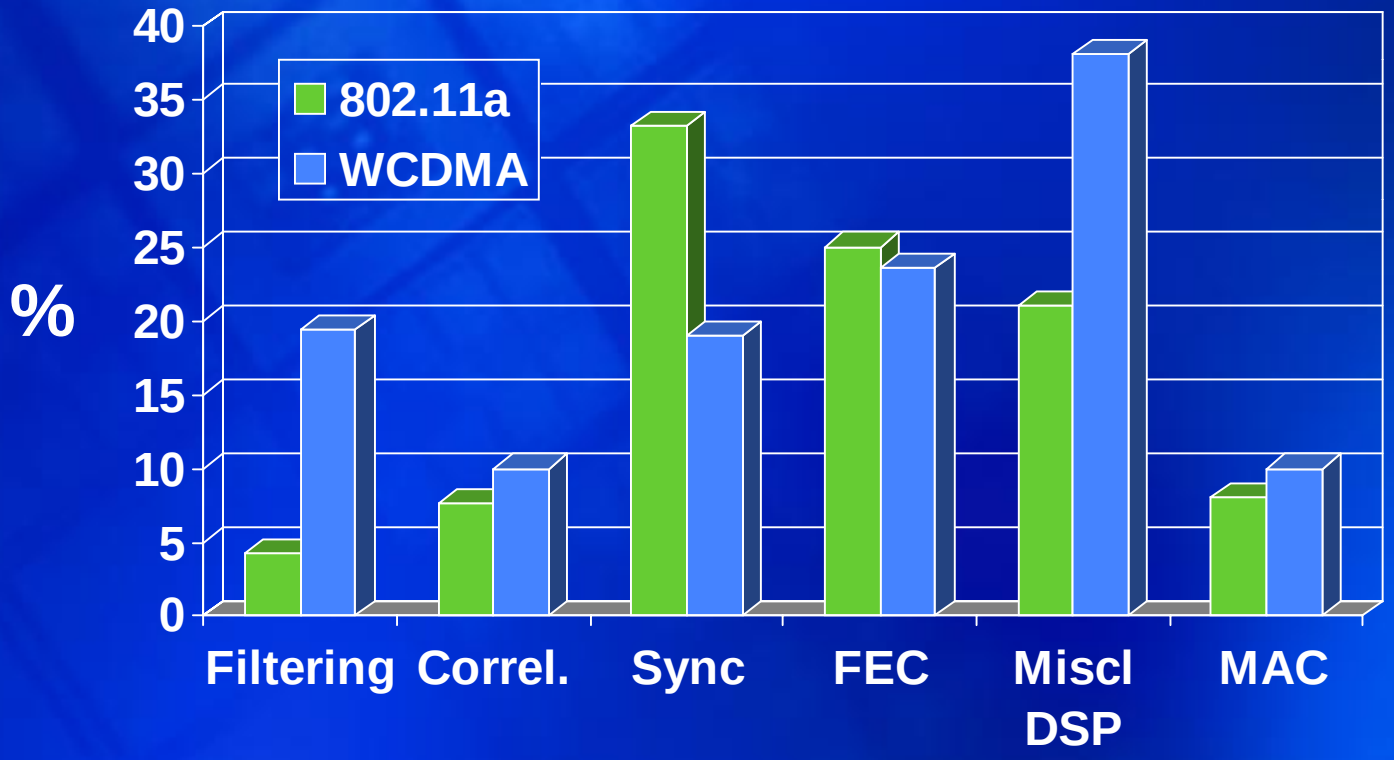
WCDMA Signal Processing Flow



Tony Chun and Hooman Honary

The high data rates in 3G result in multi-code, -antenna, and -despreader (finger) processing requirements

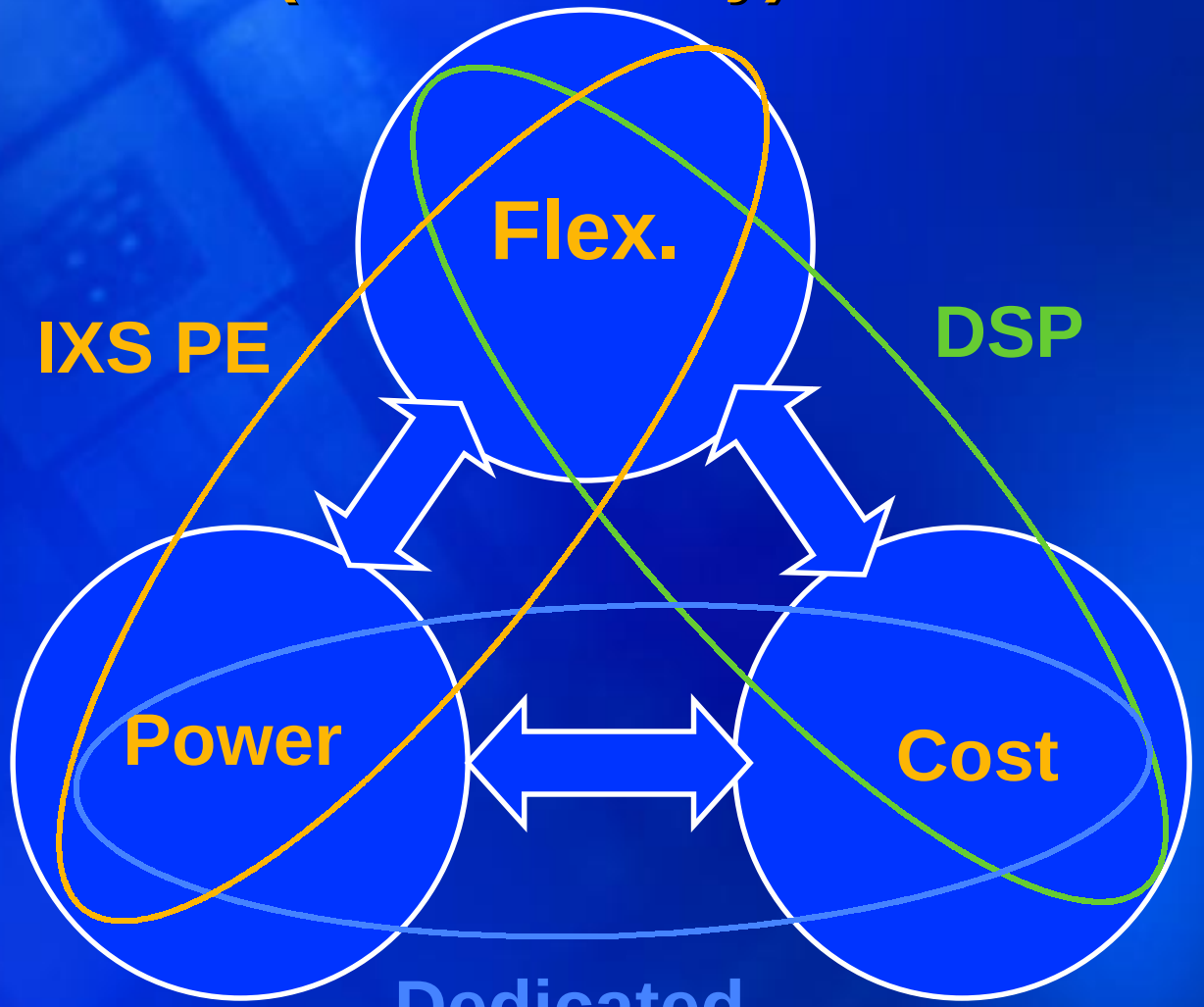
Computational Mix for Wireless Protocols



- Miscl. DSP ~ 10 separate signal processing threads

How will we go about it?

Flexibility, Power, and Cost Trades (Pick two only)



Present Status of Soft Radios

- Prior Infrastructure Approaches
  - DSP + ASIC
    - Inflexible ASIC and Costly DSP
  - DSP + Closely Coupled Accelerators
    - Increased Power and Costly DSP
  - Reconfigurable
    - Hard to Program
    - Costly
    - High Power
    - Granularity problem has not been completely solved
- Need Evolved Architecture

Architectural Objectives

- **Client:**
  - **2-3x Power/Size of Dedicated Hardware for the most intensive protocol as a goal**
  - **Related to no. of protocols possibly in the client device**
- **Basestation:**
  - **5-10x Power/Size of Dedicated Hardware for the most intensive protocol as a goal**
  - **Related to no. of protocols possibly in the infrastructure device**

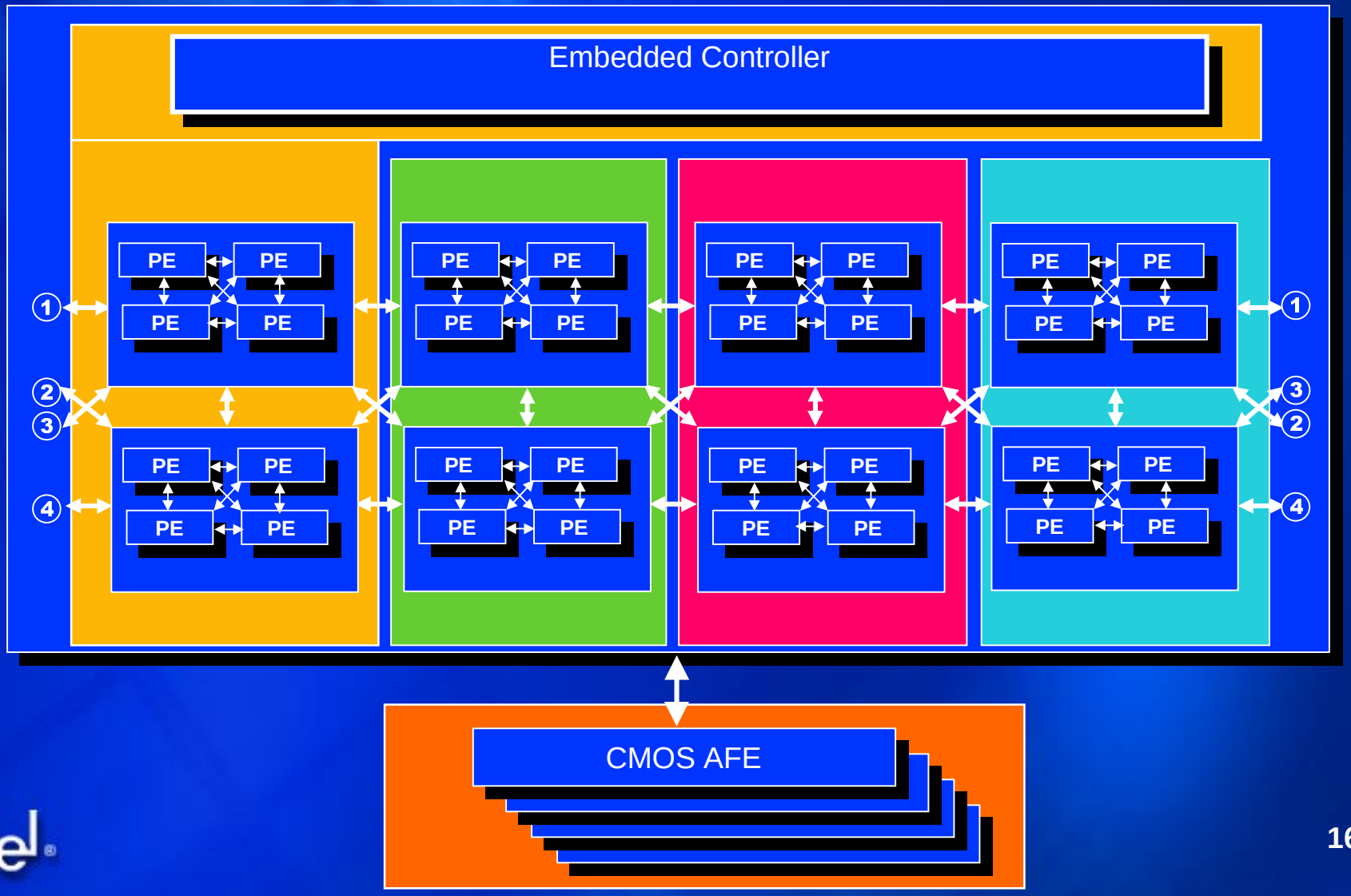
General Architectural Issues

- Low power requires a highly distributed architecture
  - Low voltage helps quadratically lower power
  - Low clock frequency linearly lowers power
  - Large size penalties associated with distributed elements must be avoided
- What is the low power interconnect strategy?
- How do we simplify the distributed processor programming problem?

Architecture Approach

- **Investigate Homogeneous Processing Elements (PE)**
  - Easy to Scale and to Program for Basestations
  - Heterogeneous better for Client
- **Interconnect with Nearest Neighbor Mesh**
  - Eliminates High Speed (and power) buses [J. Rabaey, Silicon Architectures for Wireless, Hotchips 2001 Tutorial]
  - PHY connections are 95% nearest neighbor
- **Number of Distributed Processing Elements**
  - Driven by:
    - Computational Load
    - Size and Power Constraints
    - Feature parameters, e.g., Average Load Capacitance, Vdd, etc.
- **Type of Element**
  - General Purpose DSP combined with:
  - Acceleration of “Standard Operations” with the right granularity
- **S/W programming via High Level Language**
  - Explicitly indicates parallelism and connections

System Architecture



Does a Good (near optimal) PE Solution Exist?

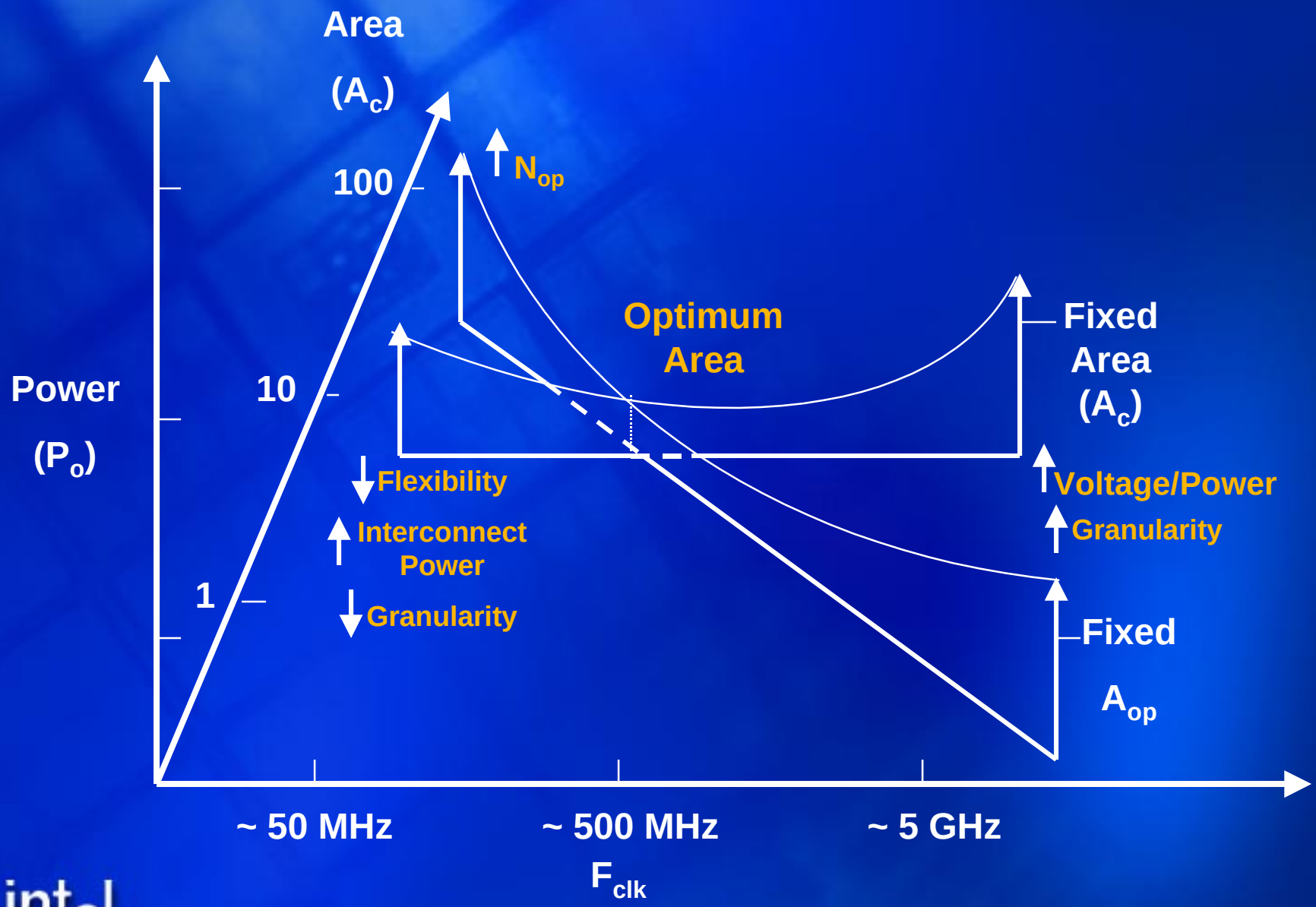
Macro-architectural Constraints

- **First, must meet Power, Size, and Computational Load constraints**
  - Computational Load = R_c (ops/sec.)
    - N_{op} = No. of parallel significant operations (multiplies, etc.) in one cycle [R. Brodersen, ISSCC'02]
    - F_{clk} = Clock frequency
    - $N_{op} \times F_{clk} > R_c$
  - Power Constraint = P_o (mW)
    - Power (dynamic, leakage (P_{leak}), short circuit (Psc)) < Po
  - Size Constraint = A_c (mm2)
    - $N_{op} \times A_{op} < A_c$
    - A_{op} = Average area of a significant computational unit (e.g., multiplier-memory-address-decoder, etc.) (mm2)
    - **Aop ~ Granularity Factor**
  - Constraints on F_{clk}
    - $R_c / N_{op} < F_{clk}$
    - $R_c \times A_{op}/A_c < F_{clk}$

Clock Rate Bounds

- **F_{clk} is upper bounded by power constraints**
  - $a \times C_{sw} \times Vdd^2 \times F_{clk} + P_{leak} < P_o/(b \times A_c)$
    - where P_{leak} is the average pwr leakage density in mW/mm2
    - C_{sw} is the average switching (load) capacitance per mm2
    - 'a' is the activity factor
    - 'b' is the average active area (incl. Datapath, cache, cache memory bus, etc. and excl. L2 memory, etc.)
    - 'b' varies from ~ 10% for microprocessors to ~ 80% for dedicated hardware and also is a function of clock gating strategies
- **F_{clk} is lower bounded by computational and area constraints**
  - **$R_c \times A_{op}/A_c < F_{clk} < (P_o/(b \times A_c) - P_{leak})/ (a \times C_{sw} \times Vdd^2)$**
  - Key Issues:
    - Find the F_{clk} that meets upper and lower bounds
    - Derive the A_{op} and N_{op}

General Power, Area, F_{clk} Trends



Reconfigurable Power Trend Summary

- **There is an optimum F_{clk} for a fixed A_{op}**
  - (Recall that A_{op} is the fundamental processing size)
  - The optimum meets Size and Computational requirements and minimizes power for the above
  - Higher F_{clk} increases power and lower F_{clk} increases area and interconnect power
- **Is there a similar optimum as A_{op} is Varied?**
  - As A_{op} decreases – interconnect Power increases exponentially
    - Simpler elements must be connected in a more complex manner to retain flexibility
  - As A_{op} increases - the voltage requirement (and Power) increases
    - More complex element requires time-multiplexing
- **Thus, is there a globally "good" design?**
  - Conjecture:
    - Determine the Minimum Aop (for the flexibility desired) and find the optimum F_{clk}

Example of "Good" Architecture Parameters in the optimum area

- N_{op} (No. of parallel Significant operations), for 90 nm:
  - N_{op} ~ 50
  - A_{op} ~ 0.6 mm^2
    - Is this an optimum Granularity A_{op}??
  - F_{clk} ~ 400 MHz
  - P_o ~ 750 mW
  - R_c ~ 20 GOPs

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Key Computing Element IXS Core

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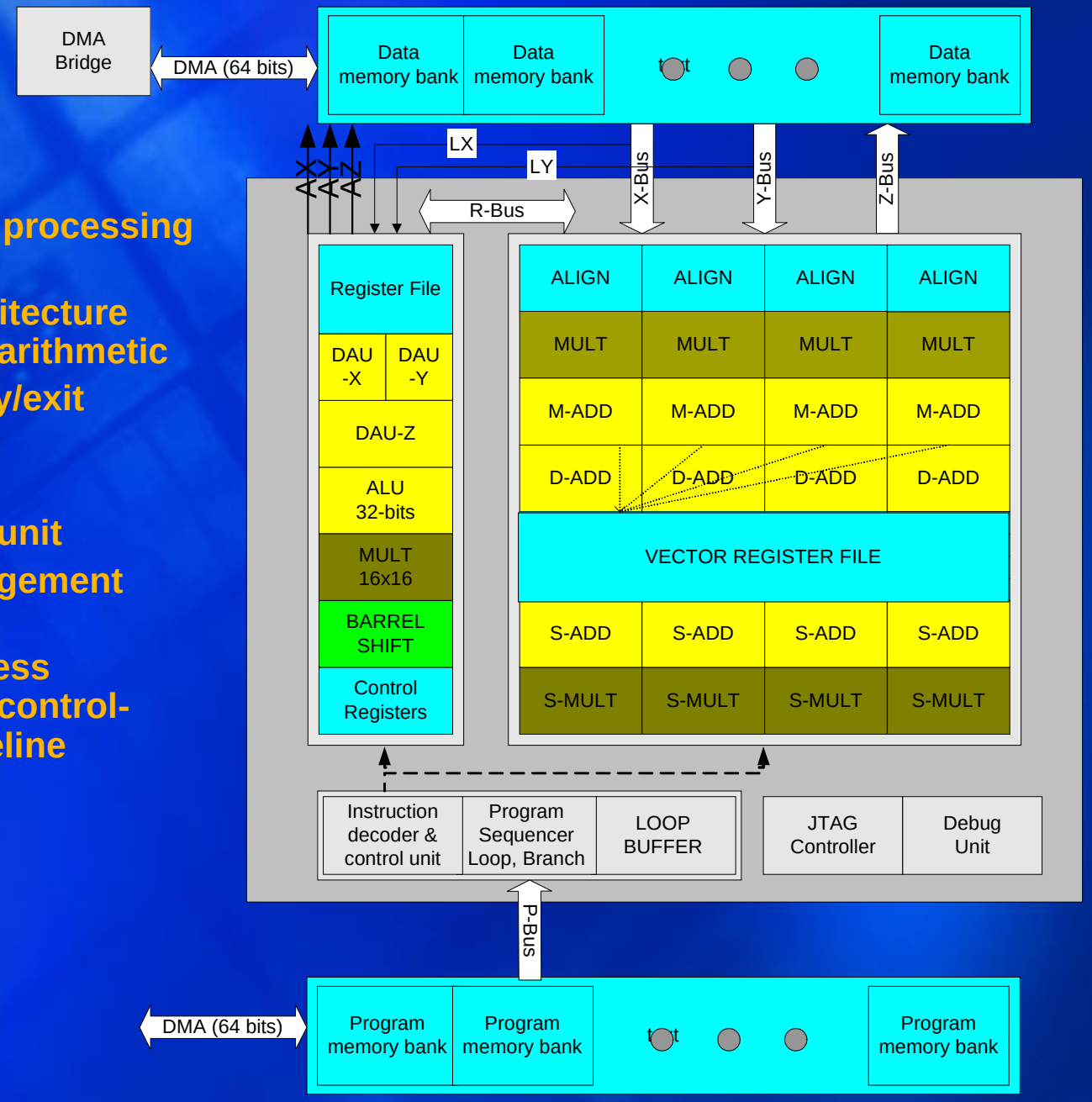
IXS core

- Efficient Vector processing architecture
- Octal-MAC architecture with 8/16/32-bit arithmetic
- Quick loop entry/exit mechanisms
- Loop buffer
- Data alignment unit
- Resource management engine
- Integrated address generation and control-processing pipeline

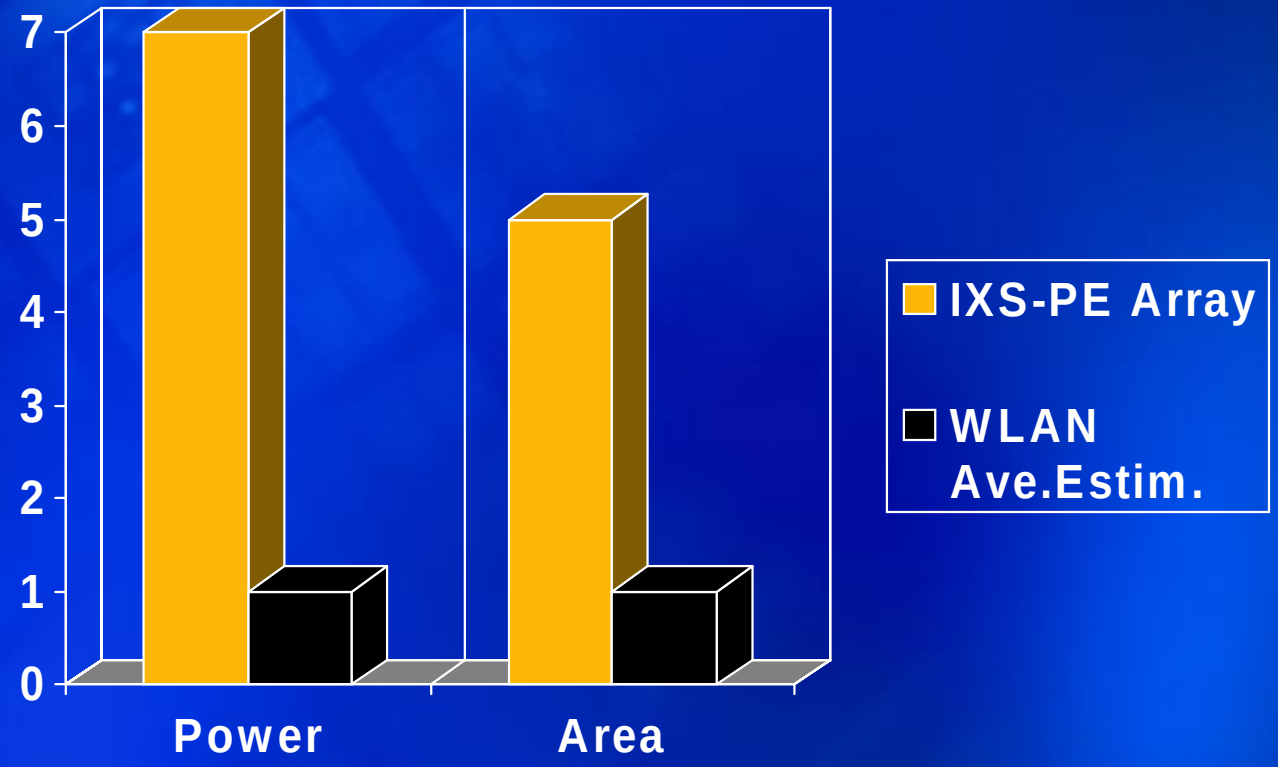


Architecture Summary

- IXS Processor Octal MAC units
  - RISC-tightly coupled
  - Acceleration H/W
    - Viterbi/Turbo
    - Correlation, De-spreading, etc.
    - Filter
  - Parameters within the N_{op} Range (50)
    - 5 PEs x 9 MACs = 45 MACs
    - 32 – 8 bit adders per PE
- Mesh-Connected to Surrounding Processors (5 PEs total)
- Do we have the optimal A_{op}?
  - Lower A_{op} will start to increase interconnect Power

How does the IXS PE Compare against Dedicated Hardware?

Power and Area Efficiency of IXS PE vs Dedicated H/W for WLAN Benchmark
Still 5-7x Dedicated H/W

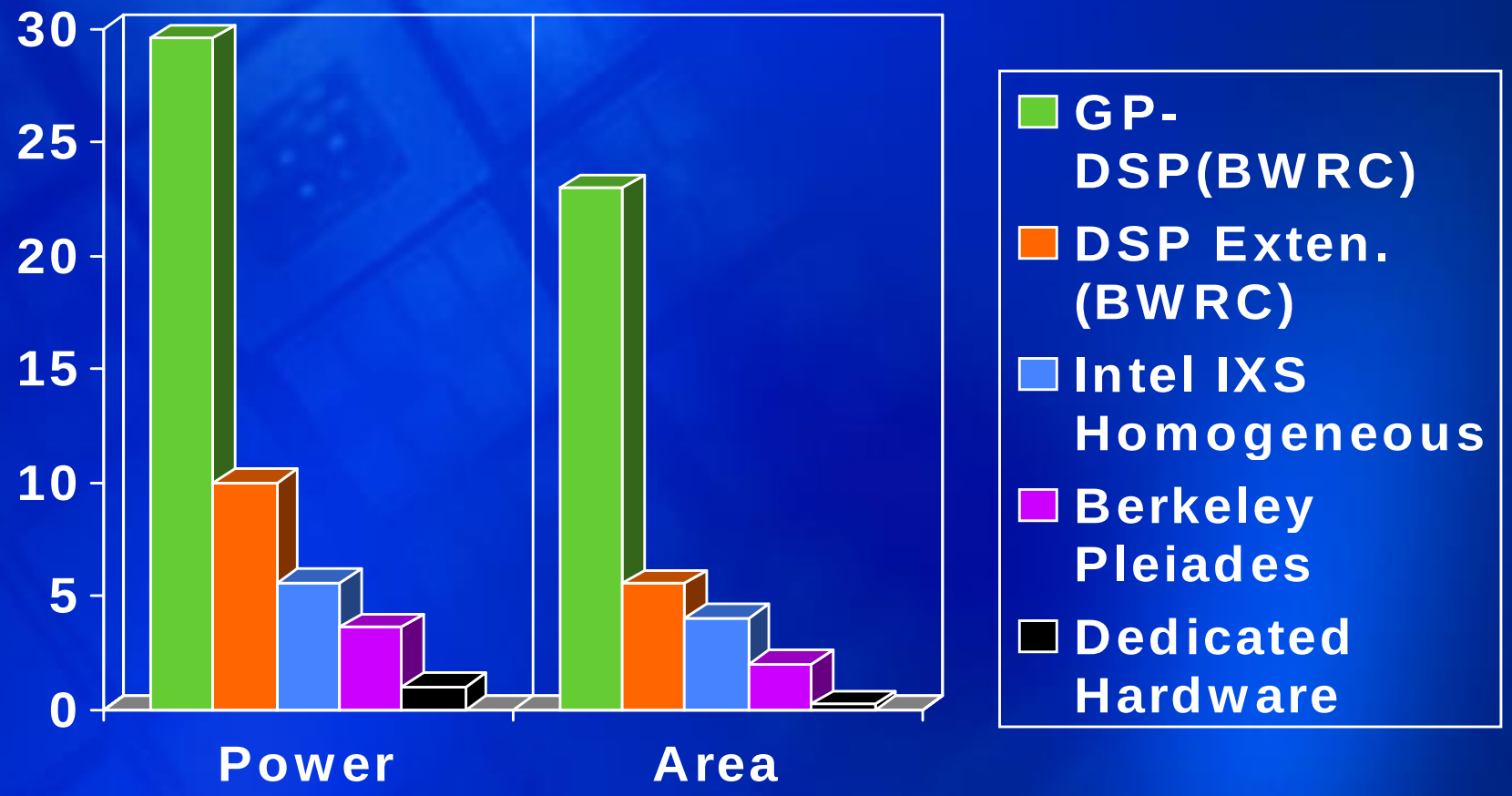


Baseband PHY and lower MAC estimates

(all scaled to 90 nm)

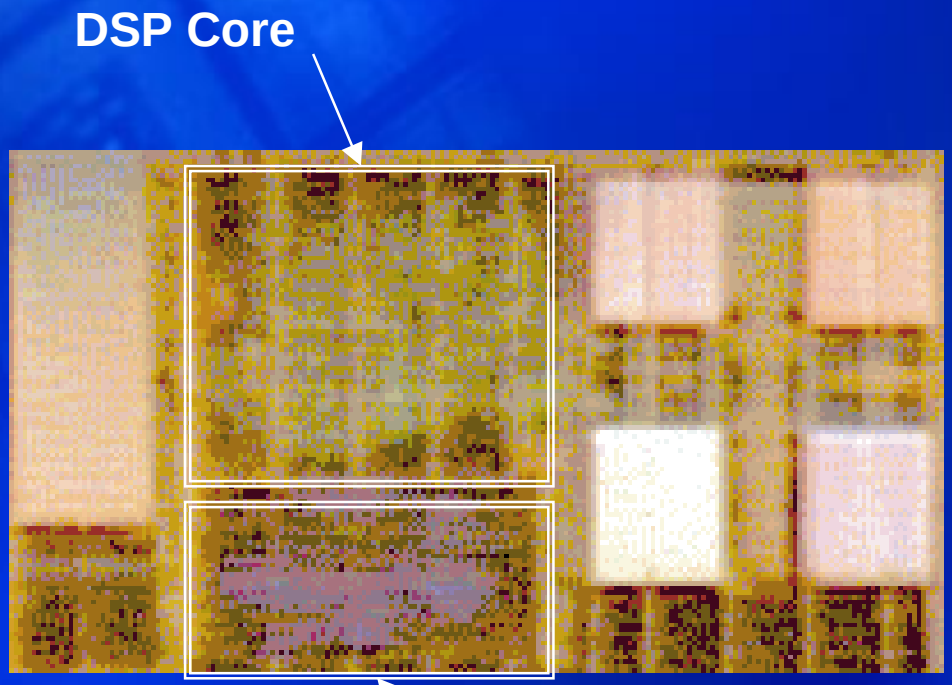
How do we compare against other Reconfigurable Approaches?

How Does our Architecture Compare?
Multi-User Detector Benchmark



BWRC and Lee Snyder

Die Photo



Summary

- Homogeneous Mesh-Connected Array of IXS Processing Elements for Infrastructure
  - Low power/size (5-7x dedicated h/w)
  - Flexibility where it's needed
  - Scaleability
  - For given size/power and feature size constraints a "good" solution can be found
  - Key Processing element
    - Minimum Memory
    - "Maximum-Datapath" Units
- Next Steps:
  - "What is the optimal A_{op} Size?"
  - "What is the right Arch. for the Client?"